TESTS OF UNIVERSALITY WITH NEUTRINOS

C. Schultz and L. M. Lederman
Columbia University

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The high intensity of ν beams at NAL offers the opportunity of making a sensitive test of μ-e universality at high energy (E > 5 BeV) and high momentum transfer. This involves the preparation of a ν_e beam, or, at least, a ν beam greatly enriched in ν_e's. Assuming we can have ν_e and ν_μ's of comparable (but known) spectra, the test would be to compile all events of the form:

$$\left.\begin{matrix}\nu_\mu \\ \nu_e\end{matrix}\right\} + (Z, A) \rightarrow \left\{\begin{matrix}\mu^- \\ e^-\end{matrix}\right. + \Gamma ,$$

where Γ is all possible hadronic final states. The test would then consist of compiling events in bins of outgoing leptonic angle and energy. The summing over all elastic and inelastic channels means that a spark chamber may be used and this compensates for the loss of intensity in preparing the beam.

Experience in the BNL neutrino run indicates that a thin (1/4 in. Al) plate massive chamber is simple to build and offers a unique means of identifying electrons since they cross ~ 14 gaps before showering--this preservation of single-track identity serves to clearly distinguish the shower from π^o - γ's generated in the reaction. The energy of the shower can be determined by spark counting. We have learned that there is good linearity here via calibration pictures in electron beams of known momentum. The difficulty is in maintaining constant spark-chamber operating conditions. On the other hand, high resolution is not required--both outgoing leptons can be put into 10% energy bins for this test.

Highly purified beams are not necessary since the detector distinguishes ν_μ events from ν_e events. Classification of the recoiling hadronic system may prove useful for more detailed comparison.

It will be important that the spectra of the ν_μ and the ν_e be as similar as possible so that the weak-interaction-theory bridge between the two experiments be leaned on as little as possible.

High-energy ν_e's are obtained from K_{e3} decays, while ν_μ's come mostly from $\pi_{\mu 2}$ decays. Assuming a π/K production ratio of $\sim 10/1$, the natural ν_e content of neutrino beams will be $\sim 1\%$. This can be increased to about 7% by selecting only neutrinos from K decays.

The "typical" ν decay angle is $1/8$, independent of decay mode. At a given momentum, the ν's from K decays come off at angles 3.5 times those of ν's from π decays. We can suppress essentially all wide-angle ν's from $\pi_{\mu 2}$ by hardening the charged π and K flux, i.e. by keeping only momenta greater than, say, 20 GeV/c. For 20-GeV K's, $1/8$ is 25 mrad. Half the ν's from 20-GeV K-decays will fall outside a 25 - mrad cone, while only 7% of the ν's from $\pi_{\mu 2}$ will do so, and the latter fraction drops off rapidly with energy, becoming 1% for 40 - GeV π decays. Moreover, the ν's from $\pi_{\mu 2}$ are $\lesssim 0.5$ GeV, while those from K-decays are ~ 4-5 GeV. A rough range requirement could easily suppress triggers from ν's of < 1 GeV.

We can harden the π and K spectra by means of a bending magnet followed by a scraper; another bend in the opposite direction will remove the dispersion. If we want to make the cutoff reasonably effective by, say, 16 GeV, we match the differential bending of 16-GeV/c and 20-GeV/c particles to the "typical" production angle of 20-GeV/c particles, $\alpha \sim (0.3\ \text{GeV/c})/20\ \text{GeV/c}$. This leads to a bend of ~ 75 mrad for 20-GeV/c particles, and an $\int Bdl$ of ~ 50 kG-m , with a magnet gap about 50 cm and a horizontal aperture of ~ 30 cm. (See also the beam of A. Krisch, B. 1-68-71).

With ν's from $\pi_{\mu 2}$ effectively suppressed, the great majority of ν_μ's come from $K_{\mu 2}$, while the ν_e's come from K_{e3}. For a given angle, the ν energy is proportional to the γ of the K and to the ν energy in the K rest frame. The latter for $K_{\mu 2}$ is 236 MeV, while for K_{e3} it is distributed in bell-like fashion around a central value of ~ 150 MeV. So we expect the energy spectra of ν_e and ν_μ to be similar in shape, with the ν_μ spectrum at about 50% higher energy than the ν_e spectrum.

Rough hand calculations of these spectra follow. We assume that the K and π-production spectra are identical and take the CKP pion spectra at 0° for the shape. We also assume that the ν_e spectrum in the K rest frame is a δ-function at $x = 0.65$, where $x = E_\nu/E_{max}$. The actual spectrum is shown in Fig. 1. Integration over the true

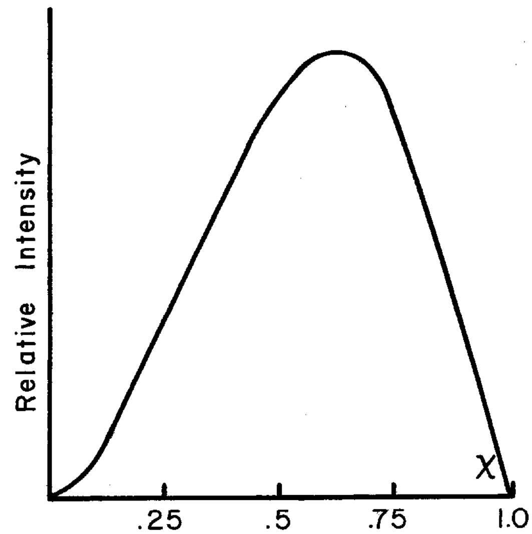

Fig. 1.

spectrum is beyond our present mathematical means. The effect on our results of considering the true spectrum will be to broaden our ν_e lab spectrum somewhat, but the latter is already so broad that this will not greatly affect our conclusions.

For the decay region we take one mean decay length for 30-GeV K's, or 220 m. The detector covers the angular region 25-35 mrad, and, if it is square, covers an area 3 m $\times$ 3 m, a lab solid angle of 10^{-4} sterad and a c.m. solid angle of ~ 0.1 sterad (for 20-GeV K decays). The center of the detector will be 10 m away from the 0° line.

The average energy and relative numbers of ν_e's and ν_μ's from the decays of kaons of several momenta are given in Table I, followed in Fig. 2 by a very approximate spectrum of the ν_e's.

The ν_μ spectrum from $K_{\mu 2}$ will be similar in shape but shifted up 50% in energy. There will also be smaller contributions, not here included, to the ν_μ spectrum, from $K_{\mu 3}$ decays (~ 5% contribution, generally at lower energies), and from $K_{\pi 2}$, τ, and τ' decays followed by $\pi_{\mu 2}$ decay. The $K_{\pi 2}$ - $\pi_{\mu 2}$ chain, in particular, could give a sizable contribution to the ν_μ spectrum. This as well as other detailed questions have to be investigated by Monte-Carlo methods.

Rate Estimate

1. In the 7-ton bubble chamber, the currently accepted estimate is 1 event/pulse,
2. In 50-ton spark chamber, 7 events/pulse (scaling by mass),
3. Fraction of ν_e in natural ν beam $\simeq$ 0.01,
4. Fraction of energy spectrum used $\simeq$ 0.5,
5. $\Delta\Omega^*/\Delta\Omega$ at 30 mrad vs 0 mrad $\simeq$ 0.2,
6. No. of K's decaying in 220 m vs 800 m $\simeq$ 0.7.

Event rate = $(7/\text{pulse}) \times 0.01 \times 0.5 \times 0.2 \times 0.7 \simeq 5 \times 10^{-3}$ ν_e events/pulse. Per 20-hour day, we get ~ 120 ν_e events. There will also be ~ 1000 ν_μ events/day.

The majority of events will have small momentum transfer and will not be useful for the universality test. For these events, however, the outgoing lepton has almost the same energy as the incident neutrino. These events will be useful for an experimental determination of the ν_e and ν_μ energy spectra. Nuclear effects cancel in the ratio which serves to normalize the high-q^2 events.

Facilities Needed

1. Ability to move the target within ~ 200 meters of the shielding wall,

2. Dispersing and recombining magnets with $\int Bdl \sim 50$ kG-m; any adequate magnet system for selecting ν or $\bar{\nu}$ would very likely be adequate for this prupose,

3. Space for setting up next to the 25-ft bubble chamber, at a distance 7 to 15 meters from it,

4. Some extra shielding in front of the detector, but the main shield will probably do most of the job, since the highest energy muons will still go in the forward direction.

Finally, we would like to emphasize one of the nicest features of this setup: it does not interfere in any way with the main neutrino beam. The experiment can be run parasitically practically any time the 25-ft bubble chamber is exposed to neutrino or antineutrino beams.

Table I. Spectrum of Neutrinos From K Decay.

P_K (GeV/c)	No. of K (relative)	Fraction of K's decaying	$\Delta\Omega^*$ (sterad)	No. of ν (relative)	Avg. energy of ν_e (GeV)	Avg. energy of ν_μ(GeV)
15	10	0.85	0.099	0.8	5.5	8.4
20	60	0.77	0.099	4.6	5.0	7.7
25	65	0.68	0.099	4.4	4.6	7.0
30	70	0.63	0.092	4.1	4.2	6.5
35	70	0.58	0.085	3.5	3.9	6.0
40	70	0.53	0.072	2.7	3.6	5.5
45	60	0.50	0.059	1.8	3.3	5.1
50	55	0.46	0.053	1.3	3.1	4.8

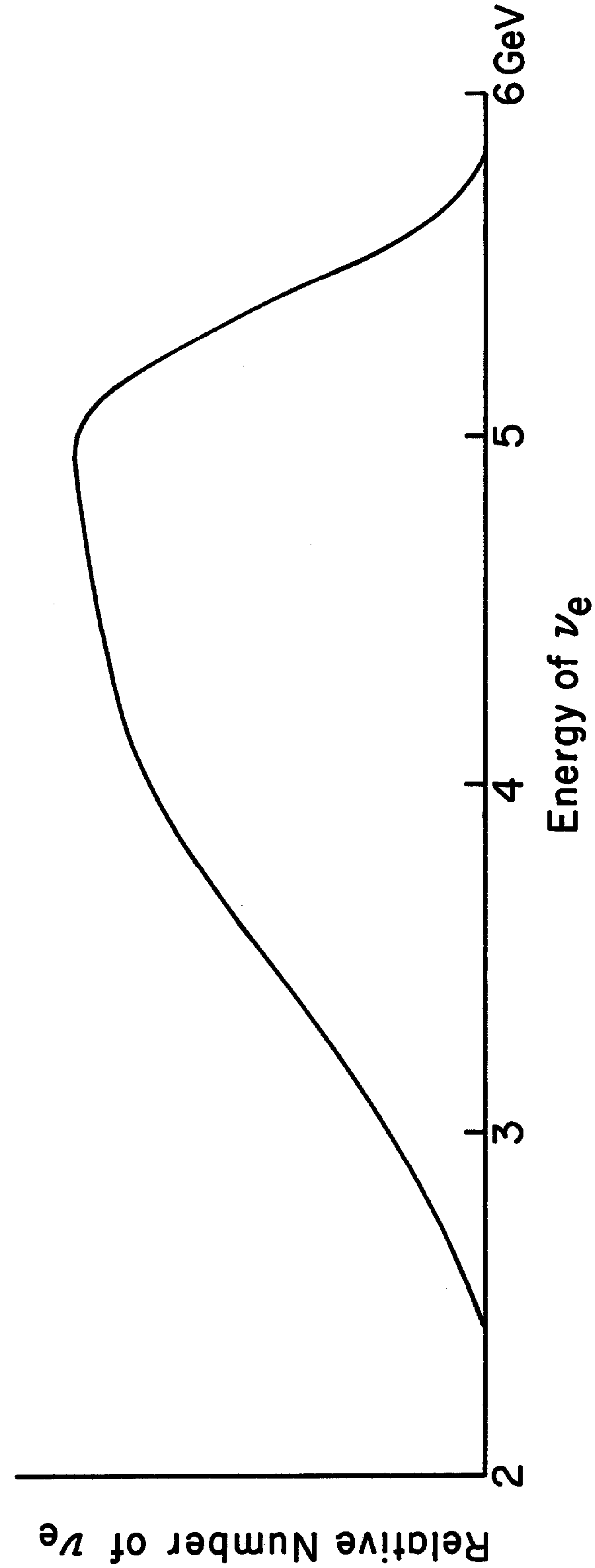

Fig. 2.